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Enhancement of Visual Target Detection With Night Vision Goggles

by William A. Monaco, Rachel A. Weatherless, and Joel T. Kalb

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14. ABSTRACT

IMPRINT (Improved Performance Research Integration Tool) was developed by the Army as a model to predict human performance in specific operational settings. This report describes an initial effort to quantify visual acuity improvement with the use of night vision goggles (NVGs) in a manner that could be incorporated into the IMPRINT model. Visual acuity was compared with NVGs and without NVGs under five specific luminance levels that the Soldier may encounter in actual battle environments. These data were then translated for use in a predictive equation for target detection. The quantified differences in Soldier target detection performance may then be applied to the IMPRINT model.

15. SUBJECT TERMS
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1. Introduction

IMPRINT (Improved Performance Research Integration Tool) (*1,2*) is a modeling and analysis tool that was developed by the U.S. Army Research Laboratory's (ARL's) Human Research and Engineering Directorate. IMPRINT is a dynamic modeling tool that uses data from a specific operational mission that has been divided into a flow of task events to accomplish the mission. A number of human performance factors may be incorporated into specific task sequences. Visual performance is one parameter that may require quantification in an IMPRINT model. Vision data, with and without night vision goggles (NVGs) in a selected range of nighttime conditions, could be incorporated into a model as one task event in a specific task sequence. Task sequences are used to effectively represent and analyze Soldier performance of a given operational scenario during a wide variety of environmental stressors.

The focus of this experiment is to quantify the degree of improvement of visual performance with NVGs, relative to unaided vision and to generate predictive data for use in the IMPRINT model. Currently, there is a need to generate data for incorporation into models of human performance that reflect the manner and extent of improvement derived with NVGs. For example, the accuracy and speed of target acquisition may be improved with NVGs. Our data demonstrate that a visual performance advantage is derived from NVGs over unaided vision in very dark settings. The data generated from this research effort may be incorporated into a predictive model such as IMPRINT. The modeler may use the quantified degree of visual acuity improvement when using NVGs instead of unaided vision in specific light levels. These visual acuity data may then be translated into a target detection scenario in a manner that predicts human detection performance for specific targets.

This experiment specifically quantifies the potential enhancement of visual performance gained with NVGs over five luminance levels ranging from 4.6E-05 footlamberts (fL) (approximately starlight) to 1.00E-03 fL (approximately a quarter moon). These light levels were selected because they represent the levels where parallel data could be obtained for aided and unaided visual performance while Soldiers are working at the limit of the unaided dark adapted eye. These data may have future applications for creating predictive visual models for determining the ranges at which targets may be detected, recognized, or identified with the NVGs. Further, our data provide a means of comparing target ranges of an observer with NVGs to those of an observer without NVGs. Differences between aided and unaided night vision may allow us to assess the ability of an observer to detect and recognize the location and direction of objects relative to himself or the objects to each other. Early target detection and localization are important to the process of perception of visual space and may facilitate safer navigation in complex operational settings. We have measured distinctions in visual capability with and without NVGs and we will demonstrate how our derived visual model may be incorporated into IMPRINT.

2. Methods

2.1 Task

To measure visual acuity in low light levels, this experiment used the high contrast form of the U.S. Air Force (USAF) 1951 tri-bar resolution chart shown in figure 1. The tri-bar chart consists of six groups of six "elements"; the elements contain three vertical and three horizontal bars. The six elements in each successive group are half the size of the elements in the preceding group. To complete the tri-bar task in this experiment, the observer reported the smallest group and element number where s/he could see the element's horizontal or vertical bars distinctly. The size of the tri-bar chart was 1 square meter.

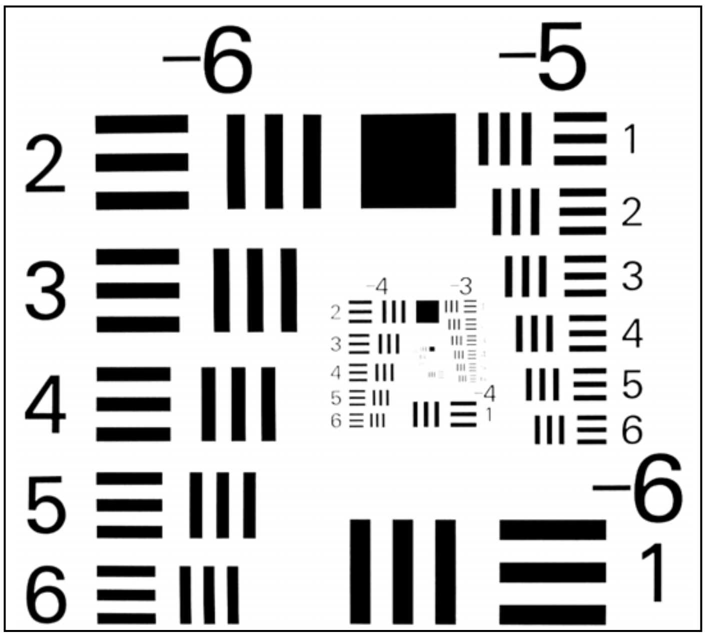

Figure 1. The USAF 1951 tri-bar resolution chart used in this study.

2.2 Experimental Design

A within-subjects design was used for this study. Three independent variables were manipulated: *view type, ocular type,* and *light level.* The *view-type* variable consisted of two levels; for the "aided" level, the observers wore an NVG to view the tri-bar chart. For the "unaided" level, the observers viewed the tri-bar chart directly. The *ocular-type* variable consisted of the three levels. The participant viewed the tri-bar chart with his left eye only, right eye only, or with both eyes. The *light-level* variable consisted of five levels: 4.60E-05, 1.00E-

04, 2.20E-04, 4.60E-04, and 1.00E-03 fL. These values represented a light level as dark as starlight to a light level as bright as a quarter moon.

2.3 Participants

Eight female and six male college students participated in this study. All observers were between 19 and 28 years of age. Each observer had 20/30 or better visual acuity (with or without correction) in each eye and normal stereopsis and color vision. Ten of the observers were from Morgan State University in Baltimore, Maryland; the other four observers were from colleges outside Baltimore.

2.4 Apparatus

2.4.1 Visual Screening

All vision screening tests were performed with the Titmus[1] vision tester.

2.4.2 NVG

The NVG used for this experiment was the AN/AVS-9[2], model F4949G, a binocular NVG. The goggle's resolution was 1.2 cycles/milliradian (approximately 20/30 acuity), with a circular 40-degree field of view and 1X magnification.

2.4.3 Chart Illumination

The tri-bar chart was back-lit with incandescent tungsten lamps of various wattages. All bulbs approximated a 2856 Kelvin black-body spectral composition. The experimenter precisely controlled the light levels by turning on or off combinations of switches to obtain the five light levels. The output produced by the chart illuminator was measured with a precisely calibrated radiometer.

2.4.4 Photometric Equipment

A model IL-1700 research radiometer was used to ensure that the light levels produced by the light level board were accurate. The actual footlambert readings were recorded for each data point taken.

2.5 Procedure

When the observer arrived for testing, s/he read and signed a certificate of informed consent. Next, his or her vision was screened to determine if the vision requirements were met. When the

[1]Titmus is a registered trademark of Titmus Optical.
[2]AN/AVS stands for Army Navy/airborne visual search equipment.

observer began the tri-bar portion of the study, the experimenter started the process with training that included procedures for focusing the goggles. The observer was then told how to view the chart though the left or through the right ocular of the NVG to obtain a monocular view.

Each observer then received training in how to read the tri-bar chart. The experimenter evaluated the observer's understanding of this training by pointing to a group and element combination on the tri-bar chart and requiring the observer to state the appropriate group and element number. This training continued until the observer reported six consecutive correct answers. The duration of this training was usually about 10 minutes.

Next, the observer was seated facing the tri-bar chart so that the tri-bar chart was positioned perpendicular to the observer's line of sight. The observer sat 3.86 meters from the chart. (This viewing distance was selected so that the smallest element on the tri-bar chart corresponded to 20/10 Snellen acuity and the largest element corresponded to 20/570 Snellen acuity.) Next, the observer adapted to the dark for 30 minutes.

In this experiment, we progressively enhanced the thresholds for acuity by increasing levels of both independent variables, that is, by wearing the NVG and also by increasing the light levels. Because of this inherent enhancement feature of the independent variables, a counterbalancing scheme for exposing levels of the independent variables to the observers would have been prohibitive[3]. In other words, lower levels of illumination could not follow higher levels without some time needed for the observers to adapt to the dark. Likewise, allowing the observers to view the chart with the NVG might affect an honest assessment of what s/he could actually see when asked to view the chart without the goggle. The experimenter therefore presented the experimental conditions in the order given in table 1 for the unaided condition. These same 30 steps were repeated for these same observers for the aided condition. Specifically, the experimenter illuminated the chart at the lowest light level. While viewing the chart with the left eye only, the observer reported the smallest discernible group and element number. The observer then stated the smallest discernible group and element number by viewing the chart with the right eye only, and finally the observer stated the smallest discernible group and element number by viewing the chart with both eyes. These three steps were then repeated. The experimenter recorded the responses along with the actual light levels produced by the chart illuminator for that trial. Next, the experimenter illuminated the chart corresponding to the next higher light level. Again, the observer gave the left-eye, right-eye, and binocular acuity responses. The experimenter continued this process until the observer had given his or her binocular acuity response at the highest light level condition.

[3]Linear regression techniques were used to control for any potential but unavoidable order or practice effects that may have resulted from this method of controlling for potential enhancement impacts of the independent variables. This technique is described in the results section.

Table 1. The 30 steps needed to obtain unaided acuity measures.

Step	Condition	Luminance (fL)	Configuration
1	Unaided	4.60E-05	Left monocular
2	Unaided	4.60E-05	Right monocular
3	Unaided	4.60E-05	Binocular
4	Unaided	4.60E-05	Left monocular
5	Unaided	4.60E-05	Right monocular
6	Unaided	4.60E-05	Binocular
7	Unaided	1.00E-04	Left monocular
8	Unaided	1.00E-04	Right monocular
9	Unaided	1.00E-04	Binocular
10	Unaided	1.00E-04	Left monocular
11	Unaided	1.00E-04	Right monocular
12	Unaided	1.00E-04	Binocular
13	Unaided	2.20E-04	Left monocular
14	Unaided	2.20E-04	Right monocular
15	Unaided	2.20E-04	Binocular
16	Unaided	2.20E-04	Left monocular
17	Unaided	2.20E-04	Right monocular
18	Unaided	2.20E-04	Binocular
19	Unaided	4.60E-04	Left monocular
20	Unaided	4.60E-04	Right monocular
21	Unaided	4.60E-04	Binocular
22	Unaided	4.60E-04	Left monocular
23	Unaided	4.60E-04	Right monocular
24	Unaided	4.60E-04	Binocular
25	Unaided	1.00E-03	Left monocular
26	Unaided	1.00E-03	Right monocular
27	Unaided	1.00E-03	Binocular
28	Unaided	1.00E-03	Left monocular
29	Unaided	1.00E-03	Right monocular
30	Unaided	1.00E-03	Binocular

The experimenter then asked the observer to use the NVG to view the tri-bar chart. The same 30 steps were repeated with the experimenter starting the trials at the lowest light level and ending at the highest light level. When the observer completed the last light-level condition, any questions that s/he may have had were answered by the experimenter, and the observer was thanked and paid for participating in the study.

3. Results

Visual acuity scores were converted by means of a logarithmic transformation to logMAR[4] units for all 14 participants. These logMAR scores were then averaged for each participant across the five light levels for each *view type* (aided or unaided) and for each *ocular-type* condition (left eye, right eye, binocular). The averages were then used in a 2 x 3 repeated measures analysis of variance.

[4]Logarithm of the minimum angle of resolution (see "Glossary of Terms" for definition).

As expected, the results indicated a highly significant effect for *view type* $F(1,13)= 2154.87$, $p <.000$. Participants' acuity was significantly better with the NVGs than without the NVGs. The main effect of *ocular type* was also significant, $F(2,26) = 39.98$, $p <.000$. A "Difference" Planned Comparison revealed that binocular acuity was significantly different from the average of the left-eye and right-eye acuity, $t(13) = 76.44$, $p = .004$. As expected, results indicated no significant difference in acuity between the left and the right eye. The interaction of *view type* and *ocular type* was insignificant.

The data were then compiled into a matrix comprised of 14 individual acuity scores for each of the five selected luminance levels under aided and unaided conditions, and these data were incorporated into a regression model. The model yielded the "average person's" visual acuity obtainable within the range of light levels selected in the experiment. These data were also shown to follow a psycho-physical power law of the luminance consistent with the following equations:

$$y_{(individual)} = Y_{(mean)} + \beta_{(mean)} (x_{(individual)} - x_{(mean)})$$

in which $y_{(individual)} = \text{logMAR} = \log_{10} (1.719 \text{ cycles per milliradian}/\text{VA}^{5} \text{ in cycles per milliradian})$
$x_{(individual)} = \log_{10} (L_{individual}/L_{mean})$
β = the slope
L = luminance in footlamberts

In combining these equations, we derived a general equation for the power law of the luminance for unaided and aided visual acuity:

$$VA_{(individual)} = VA_{(mean)}(L_{(individual)}/L_{(mean)})^{-\beta}$$

Specifically, the power law of the luminance for binocular unaided vision is

VA (Binocular Unaided) = $1.88L^{0.347}$ cycles per milliradian

and for binocular aided vision is

VA (Binocular Aided) = $3.42L^{0.130}$ cycles per milliradian

and for monocular aided vision is

VA (Right, Monocular Aided) = $3.38L^{0.141}$ cycles per milliradian

VA (Right, Monocular Unaided) = $1.05L^{0.294}$ cycles per milliradian

VA (Left, Monocular Aided) = $3.38\ L^{0.138}$ cycles per milliradian

VA (Left, Monocular Unaided) = $1.04^{0.293}$ cycles per milliradian

A complete summary of all the power law equations and their corresponding data plots is depicted next.

[5]VA = a measure of visual capability of the subject.

At the lowest luminance level, half of the subjects did not respond, while the acuity of the responders fell within the predicted confidence interval with one exception. Since no tri-bars were presented with a logMAR higher than 1.45, the distribution of responses is seen to be truncated at that level.

This psycho-physical model was then incorporated into a model for prediction of detection range that was proposed by Johnson (*3*) to provide insight into the detection range differences with and without goggles in monocular and binocular viewing conditions.

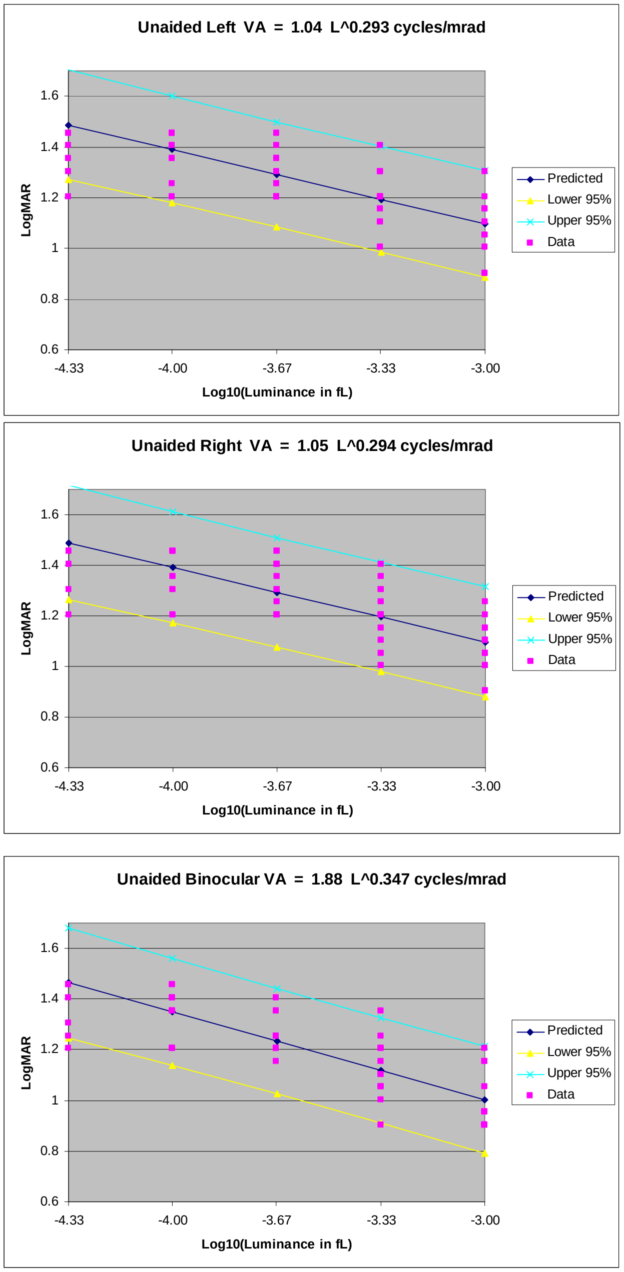

Figure 2. Plots are shown for 95% confidence intervals on predictions made by a linear regression model based on subject logMAR acuity for the four highest luminance levels.

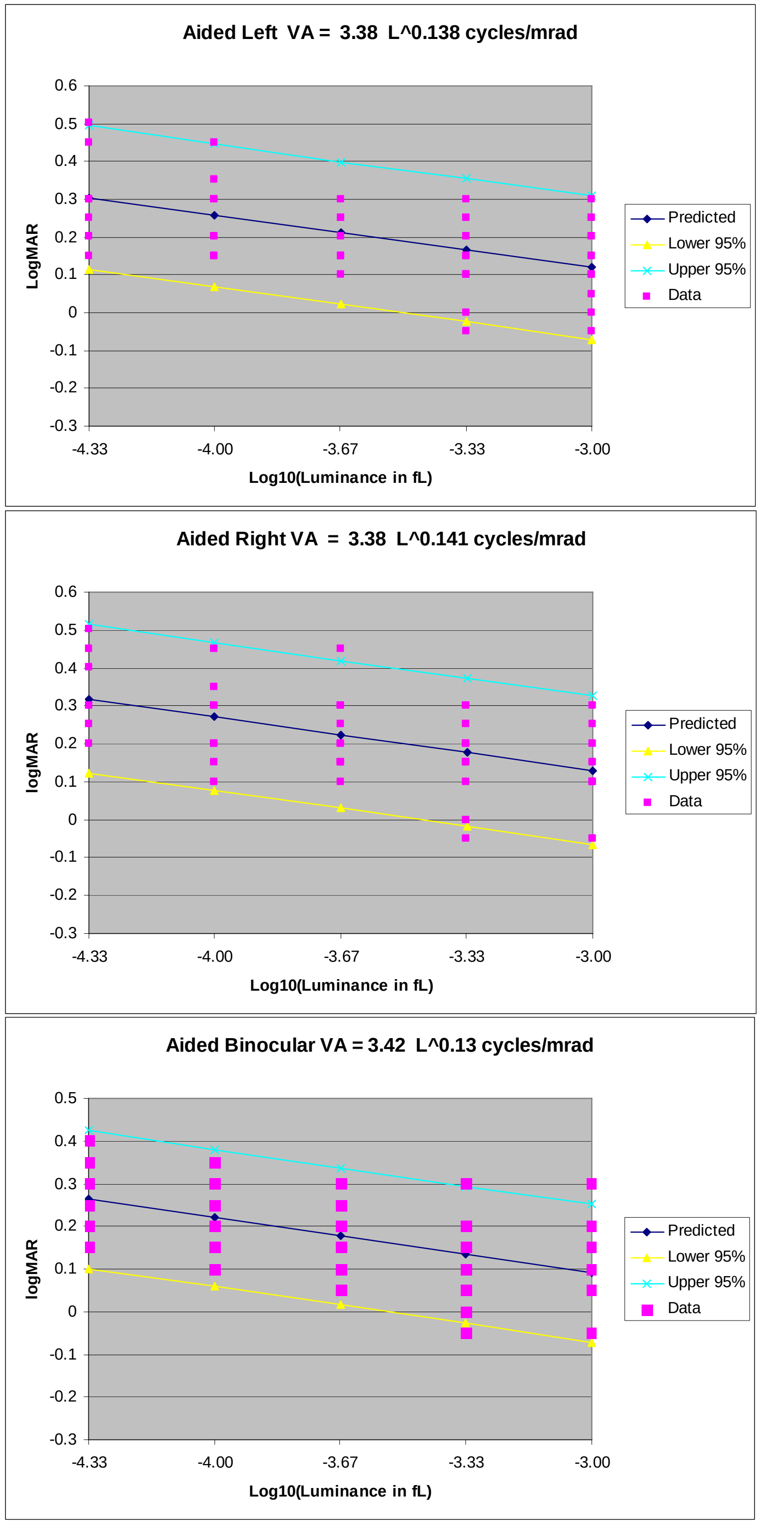

Figure 3. Plots are shown for 95% confidence intervals on predictions made by a linear regression model based on subject logMAR acuity for five luminance levels. (The measured acuity fell within the predicted confidence intervals.)

Johnson Model: Range of Detection (meters) = 1000 (D) (VA) / C

Where:
D = Critical Target Dimension (given as 0.4 meter for a human target)
C = Johnson criteria (1.5 cycles across the critical dimension of the target, i.e., standing Soldier)

The Johnson model provides a prediction of performance of a given task based on ensemble or group performance data, thereby allowing performance predictions based on the average observer.

Example depicting the detection range of monocular and binocular NVGs over unaided vision in a given light condition:

"What is the approximate range advantage for detection of a Soldier target by the average observer or group of observers with and without NVGs under quarter moon conditions? "What detection range difference is there between monocular and binocular NVG?"

Range of Detection (Soldier) with **Binocular** NVGs = 1000 (D) (VA) / C
= 1000 mrad (0.4 meters) [3.42 (1/4 moon luminance)$^{0.130}$ cycles/mrad]/ 1.5 cycles
= 400 mrad-meters [3.42 (0.001)$^{0.130}$ cycles/mrad]/ 1.5 cycles
= 400 mrad-meters [3.42 (0.407) cycles/mrad]/ 1.5 cycles
= 400 mrad-meters [1.39 cycles/mrad] / 1.5 cycles
= **372 meters**

Range of Detection (Soldier) without NVGs (**Binocular**) = 1000 (D) (VA) / C
= 1000 mrad (0.4 meters) [1.88 (1/4 moon luminance)$^{0.347}$ cycles/mrad] / 1.5 cycles
= 400 mrad-meters [1.88 (0.091) cycles/mrad]/ 1.5 cycles
= **46 meters**

Range of Detection (Soldier) with **Monocular** NVG = 1000 (D) (VA)/ C
= 1000 mrad (0.4 meters) [3.38 (0.001)$^{0.141}$ cycles/mrad]/ 1.5 cycles
= 400 mrad-meters [3.38 (.378) cycles/mrad]/ 1.5 cycles
= **340 meters**

Our derived model of visual detection predicts a range advantage with binocular NVGs of approximately 326 meters or an eight-fold improvement over unaided binocular vision under quarter moon luminance conditions. The detection range advantage is less (approximately 294 meters) with monocular NVG viewing, and there is a seven-fold improvement over unaided binocular vision. These data may be generalized to other targets (e.g., Abrams tank, Bradley armored personnel carrier and high mobility multipurpose wheeled vehicle [HMMWV]), provided the optical image transformations (lines across the target) are calculated.

Table 2. Detection range for targets viewed with and without NVGs during quarter moon luminance conditions.

Goggle Wear	Light level	Soldier	HMMWV	M-1 Abrams	M-3 Bradley
With NVG	¼ Moon	340 m	1950 m	4040 m	5050 m
Without NVG	¼ Moon	36.7 m	210 m	437 m	546 m
Johnson Criteria (cycles on target)		1.5 cycles	1.2 cycles	0.75 cycles	0.75 cycles
Target Minimum Dimension		0.4 meter	1.83 meters	2.38 meters	2.97 meters

4. Discussion

Our data clearly demonstrate a significant improvement in visual acuity with AN/AVS-9 Model 4949G NVGs over unaided vision at all of the luminance levels selected. Further, in accordance with existing well-established clinical data, binocular vision is better than monocular vision aided or unaided. Also, as luminance increases, the unaided visual acuity was demonstrated to improve more rapidly than aided acuity. This may be explained by a greater number of photoreceptor cells remaining adapted to the dark in the unaided condition and then being stimulated at an exponential rate as light levels were increased. This finding may be confirmed by visual inspection of the plotted data where it is noted that the slope (β) for unaided acuity is consistently greater than for the aided acuity (see figures 2 and 3).

Our original goal was to quantify visual acuity improvement derived from the use of NVGs in specific luminance conditions and then translate those data into predictive equations for incorporation into the IMPRINT model. We have derived and tested the effectiveness of our predictive model across median acuity values (in VA), at given luminance levels, for this population of participants. We have provided an example of improved target detection performance with NVGs by applying our power law to Johnson's predictive model for target detection performance.

Finally, it is possible to observe the impact on an individual's visual performance by selecting and analyzing data from a single subject. The following example demonstrates the value of NVGs in improving an individual's night vision performance:

Using Subject 9 (see figure 4) as an example, we can compare binocular acuity with and without NVGs at the lowest light level (4.60E-05fL). Binocular unaided visual acuity translates to 20/570, whereas visual acuity with NVGs improves to 20/36 for this individual. The visual acuity difference represents a 16-fold increase in visual function. At the highest light level selected (1.00E-03fL), the unaided binocular visual acuity is 20/160 and the acuity improves to 20/25 with NVGs. The visual acuity difference represents a 6.4-fold increase in visual function. These data quantify the quality of visual acuity improvement for this individual and demonstrate that NVGs provide the most dramatic improvement in visual function at levels where unaided vision is significantly degraded. Visual acuity improvement trends were exhibited in similar degrees for all 14 of the study participants.

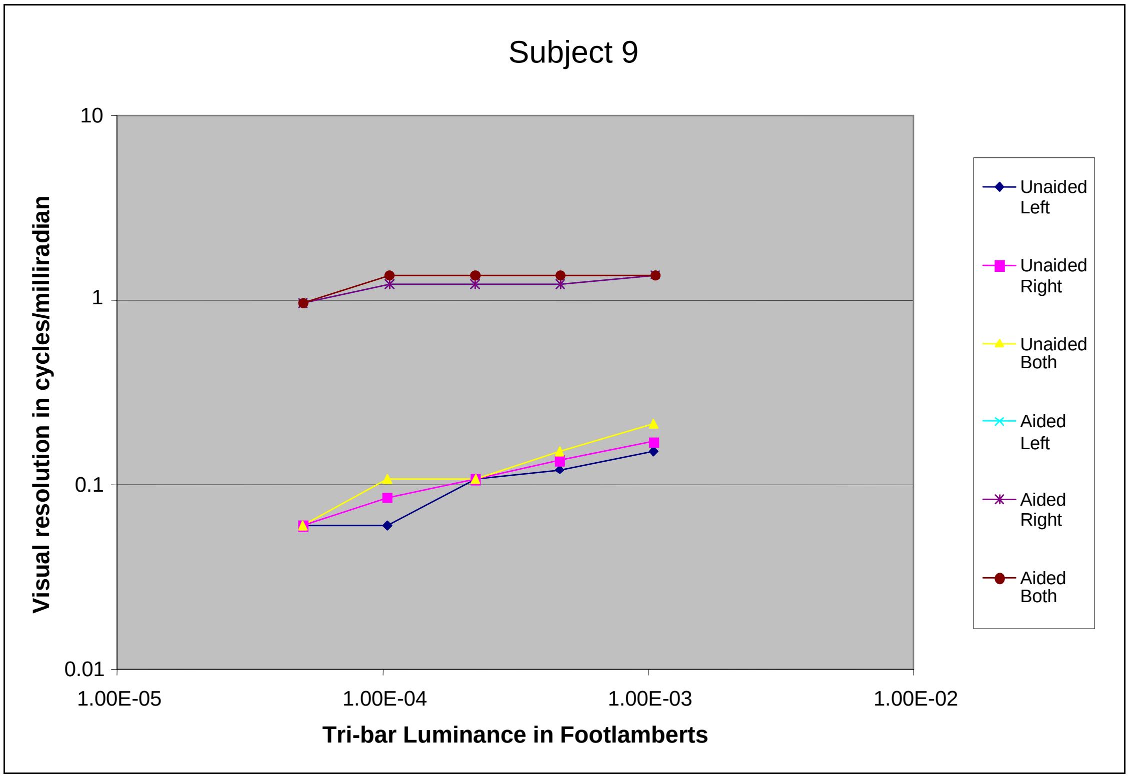

Figure 4. Example depicting the differences between binocular visual acuity with and without NVGs at the five selected luminance levels.

5. Conclusions

This report describes an initial effort to translate specific visual performance data in a manner that may be used in the IMPRINT model. Our data clearly demonstrate that there is significant visual improvement when NVGs are used at the selected light levels. These data were incorporated into the Johnson target detection model, and actual target detection ranges were calculated. The improved target detection range with NVGs allows us to suggest that these data increase the time available for decision making and target recognition in specified light levels. These data may be used by IMPRINT modelers for a given operational task analysis. As demonstrated in table 2, the IMPRINT user would select one of the five lighting conditions (with or without NVGs) calculate the desired target's minimum dimension, and derive its detection range. The impact that darkness (defined as a "stressor" in the IMPRINT model) has on target detection range could be quantified with and without NVGs. Reaction time could be calculated from the detection range and incorporated into IMPRINT. Then, the IMPRINT modeler could compare the differences in length of reaction time and more precisely predict Soldier performance in given environmental conditions.

6. References

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Glossary of Terms

Log of the minimum angle of resolution (logMAR): Most modern visual acuity charts are designed so that the letters on each line follow a geometric progression, i.e., each line represents a uniform step on a logarithmic scale. The geometric progression most accurately represents the manner in which the human visual system functions. The typical step progression is 0.1 log unit, which corresponds to the letter changing in size by a factor of 1.2589. The simplest and most widely accepted means of performing statistical analyses on visual acuity data is to convert the visual acuity of each participant to logMAR. The conversion equations are

logMar = - log (visual acuity in decimal connotation)

decimal acuity = antilog (-logMAR) = $10^{-\text{logMAR}}$

Cycles per milliradian (VA): A measure of resolution. A milliradian is the angle subtended by an object whose height is one yard viewed at a distance of 1,000 yards. One cycle/milliradian resolution is required to detect a separation of 0.5 yard between two objects that are 0.5 yard in size.

Luminance: The amount of light per unit area reflected from or emitted by a surface. Luminance can be expressed in a variety of units. For this experiment, we selected footlamberts.

Acuity Conversion Table

SNELLEN	logMAR	CPMRAD	SNELLEN	logMAR	CPMRAD	SNELLEN	logMAR	CPMRAD
20/400	1.30	0.086	**20/270**	1.13	0.127	**20/140**	0.85	0.246
20/390	1.29	0.088	**20/260**	1.11	0.132	**20/130**	0.81	0.264
20/380	1.28	0.090	**20/250**	1.10	0.138	**20/120**	0.78	0.286
20/370	1.27	0.093	**20/240**	1.08	0.143	**20/110**	0.74	0.313
20/360	1.26	0.095	**20/230**	1.06	0.149	**20/100**	0.70	0.344
20/350	1.24	0.098	**20/220**	1.04	0.156	**20/90**	0.65	0.382
20/340	1.23	0.101	**20/210**	1.02	0.164	**20/80**	0.60	0.430
20/330	1.22	0.104	**20/200**	1.00	0.172	**20/70**	0.54	0.491
20/320	1.20	0.107	**20/190**	0.98	0.181	**20/60**	0.48	0.573
20/310	1.19	0.111	**20/180**	0.95	0.191	**20/50**	0.40	0.688
20/300	1.18	0.115	**20/170**	0.93	0.202	**20/40**	0.30	0.859
20/290	1.16	0.119	**20/160**	0.90	0.215	**20/30**	0.18	1.146
20/280	1.15	0.123	**20/150**	0.88	0.229	**20/20**	0.00	1.719

*CPMRAD = cycles per milliradian

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